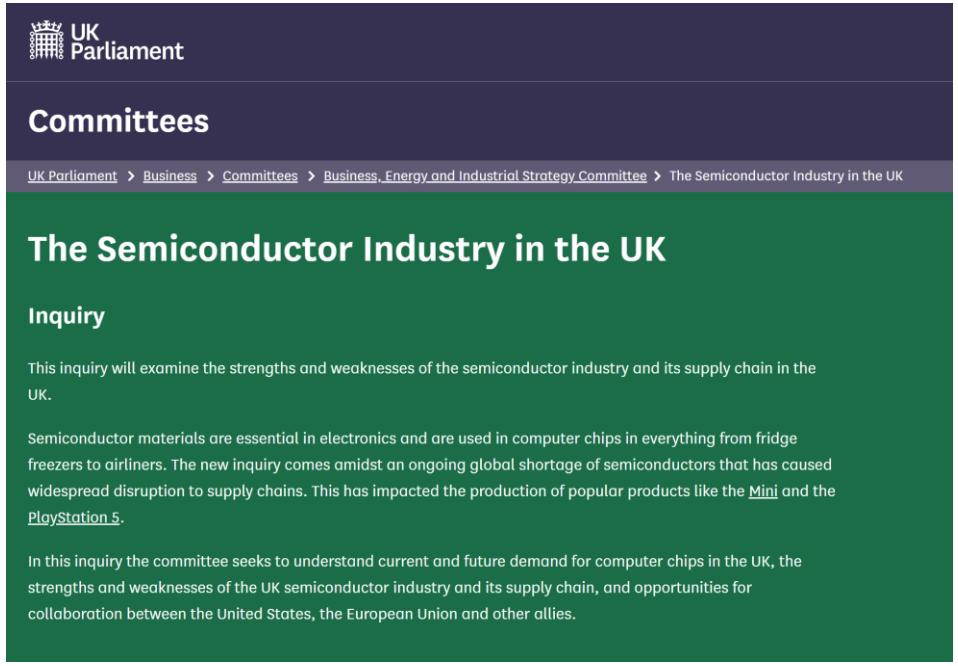
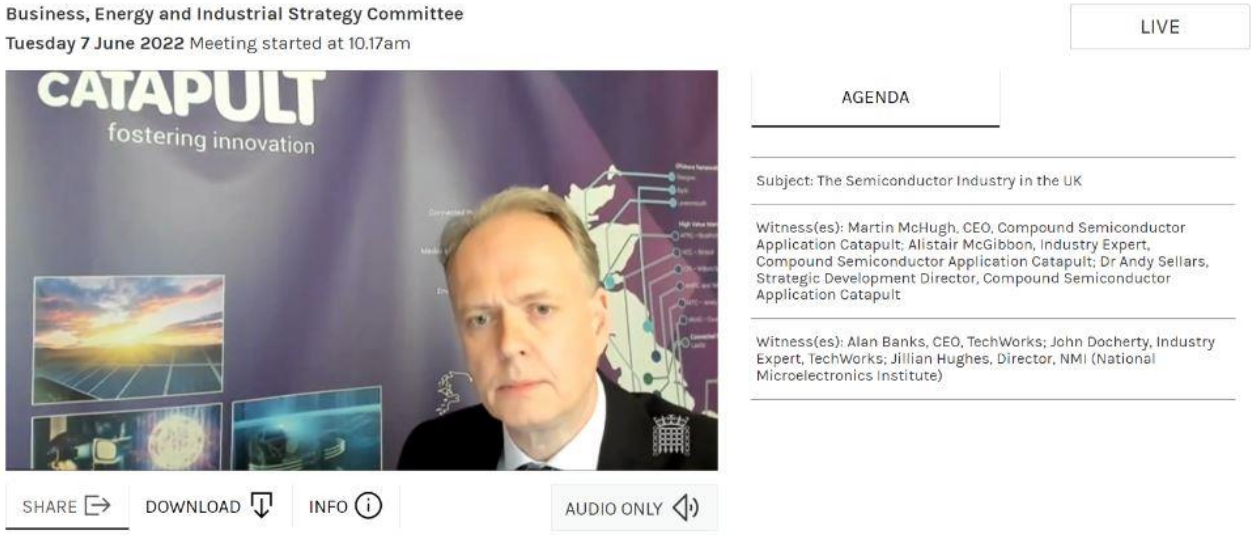
CATAPULT
Compound Semiconductor Applications

Building resilient semiconductor supply chains

Dr Andy G Sellars
Manufacturing and Engineering Week
9 June 2022

UK semiconductor consultation



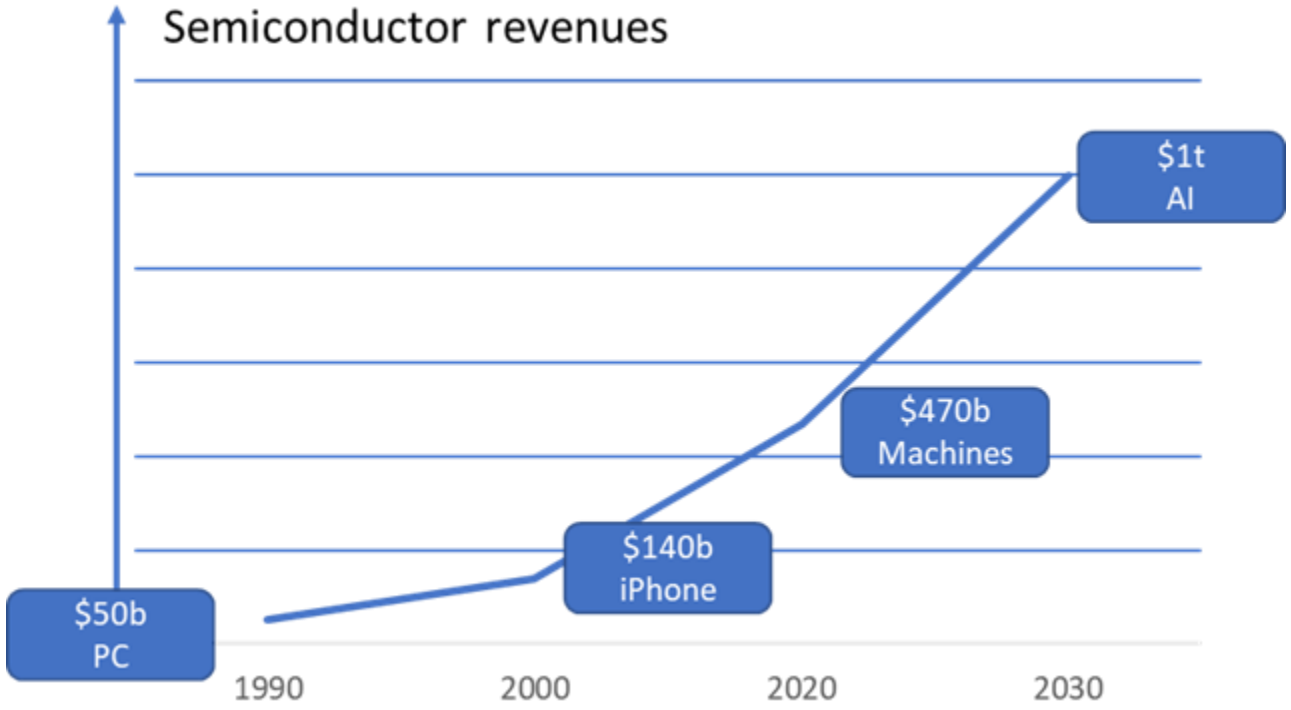


[Parliamentlive.tv - Business, Energy and Industrial Strategy Committee]

[The Semiconductor Industry in the UK - Committees - UK Parliament]

Deadline: 14 June 2022

Exponential growth



[PowerPoint Presentation (appliedmaterials.com)]

Timeline

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Compound Semiconductor Applications

2013

National semiconductor strategy
Consultations with 200 companies, 50 universities

2014

2015

Business case to
HM Treasury

2016

Chancellor's
announcement

2017

Property search

2018

Prime Minister's roundtable
on electric vehicles

2019

State of the art facilities

2020

Official opening
Royal Society

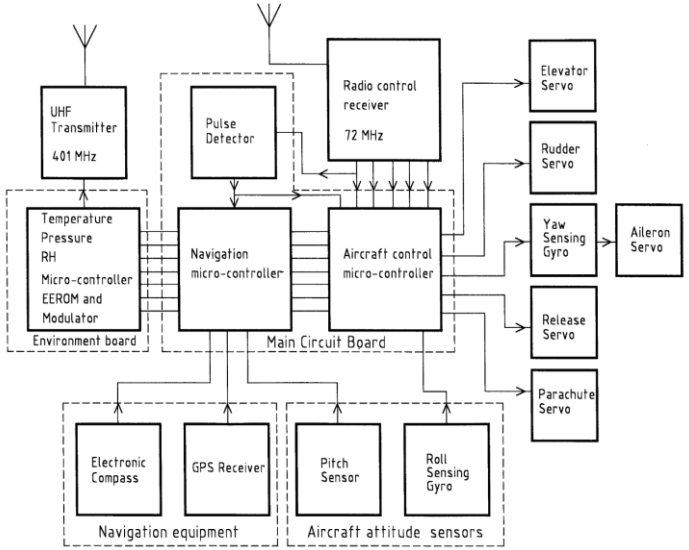
2021

International partnership
with ITRI, Taiwan

2022

Driving Electric Revolution
Industrialisation Centre

Electronic systems

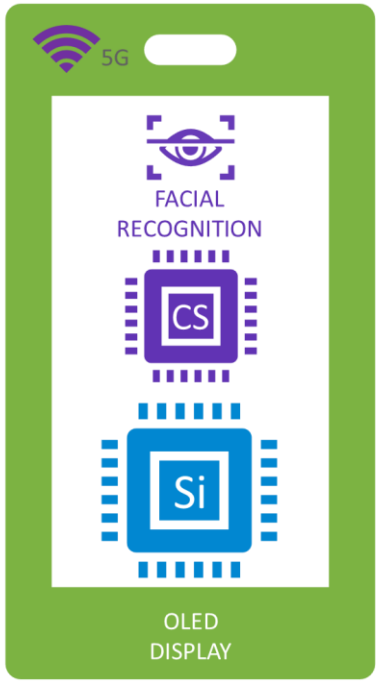


Electronic system	Biologic equivalent
Microcontroller / microprocessor	Brain
Memory	Memory (part of the brain)
Software	Neuron interconnect
Sensor(s)	Eyes, ears, tongue, etc
Servo	Arms, legs, etc
Transmitter / receiver	Vocal chords / ears
Battery	Muscles / body fat

Semiconductors – segmented by material

Silicon (Si) semiconductors	Compound semiconductors (CS)	Other semiconductors (2D, organic, thin film)
Discrete transistors Logic Amplifiers Microcontrollers / microprocessors Mixed signal	Power transistors (MOSFETs etc) RF amplifiers Lasers Imaging Single photon sources (quantum) Single photon detectors (quantum)	Displays (laptop, phone) Solar panels (perovskites) Novel flexible microprocessor demonstrated by ARM/PragmatIC Flexible Processors? Arm and PragmatIC Push Flexible Electronics Up A Level - News (allaboutcircuits.com) Novel sensors (graphene)

Electronic systems



- Silicon (Si): main functions, typically 70-80% of semiconductor value
- Compound (CS): specialist functions, typically 10-20% of semiconductor value
- Other (OLED): display functions, typically 5-10% of semiconductor value

Examples

Product	Manufacturing cost	Semiconductor value	Si (%)	CS (%)	Other (%)
iPhone	$570	$350	80%	10%	10%
Tesla powertrain	$3,900	$1,950	20%	65%	5%
Data centre server	?	$5,600	90%	>5%	<5%

Apple iPhone 13 Pro Teardown | TechInsights
PowerPoint Presentation (cargroup.org)
PowerPoint Presentation (appliedmaterials.com)

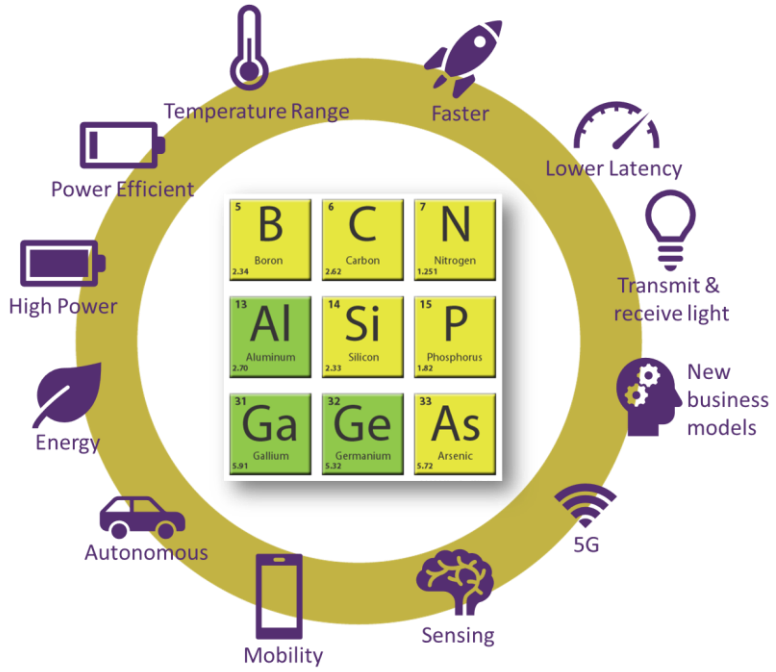
Silicon semiconductors – segmented by lithography

Category	Lithography or node (smallest transistor)	Typical chips	Cost to build a fab
Legacy Introduced before 2000	> 90nm Up to 10m transistors per chip	From single discrete transistors that switch power to complex chips with millions of transistors capable of running basic software	< £100m
Mainstream Introduced between 2000 and 2010	28nm – 90nm Up to 1bn transistors per chip	Highly functional chips capable of processing complex signals and running complex software	£200m – £1bn
Leading edge Introduced after 2010	< 28nm Up to 100bn transistors per chip	Extremely complex chips that may combine multiple **mainstream** chips in one device, capable of running complex software	$5bn – $20bn

Lithography refers to the dimension of the transistor, which is the building block of electronics. Transistor dimensions are measured in nanometres (nm). As the lithography size decreases, more transistors can be fabricated on a chip, creating more functionality on the chip.

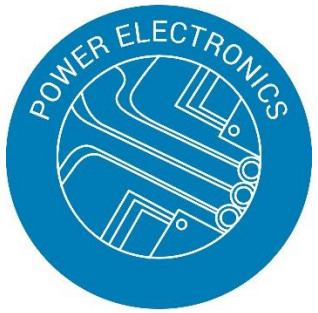
Silicon vs compound semiconductor chemistry

Type	First element	Second element
Binary III-V (**most important**)	Group III (aluminium, boron, gallium and indium)	Group V (antimony, arsenic, nitrogen, phosphorous)
Binary II-VI	Group II (cadmium and zinc)	Group VI (oxygen, sulphur, selenium and tellurium)
Binary IV-VI	Group IV (lead and tin)	Group VI (sulphur, selenium and tellurium)
Binary V-VI	Group V (bismuth)	Group VI (tellurium)
Binary II-V	Group II (cadmium, zinc)	Group V (antimony, arsenic and phosphorous)



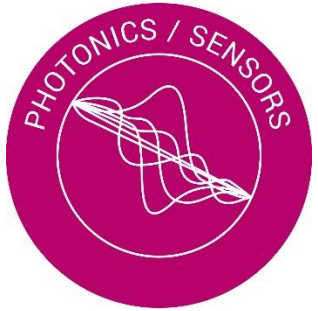
- Silicon is a single element: possible to make large, very pure wafers
- CS are a combination of 2 or more elements: more difficult to control

Compound semiconductors outperform silicon in 3 areas

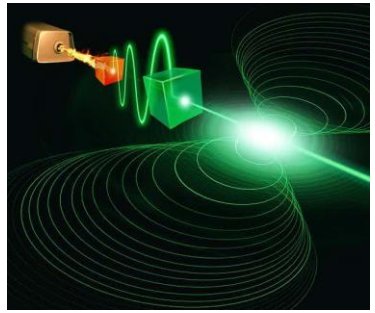


Power: electric vehicles, smart grids
Eg GaN and SiC

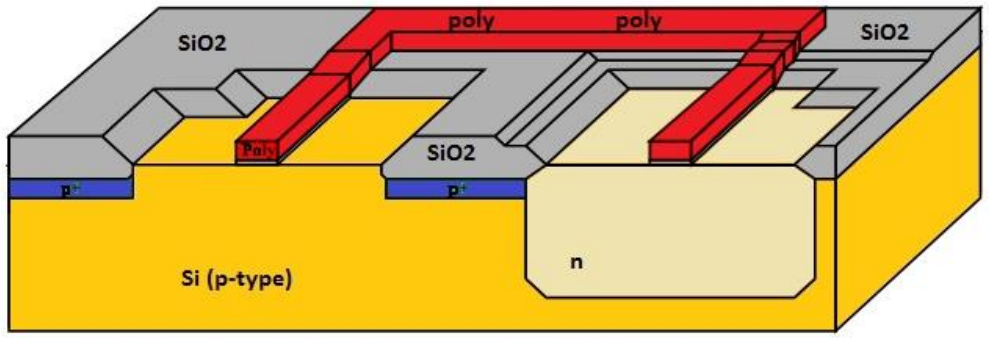
Speed: satellite communications & 5G
Eg GaAs and GaAs



Light: quantum, imaging
Eg InP and CdT

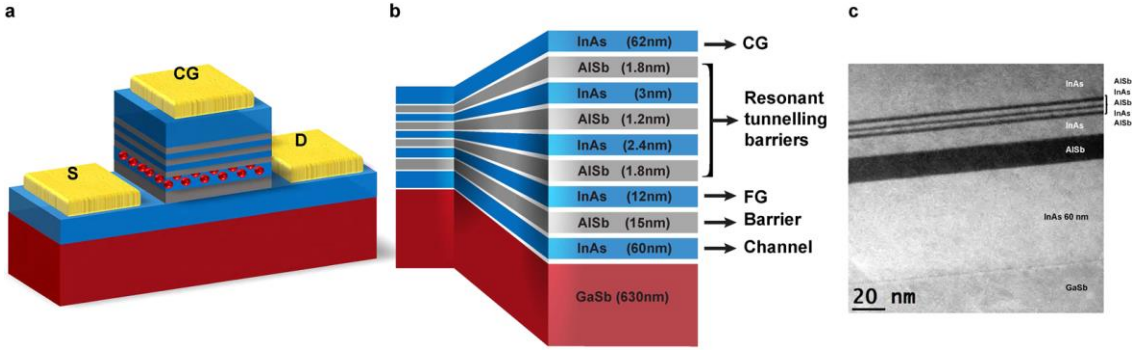


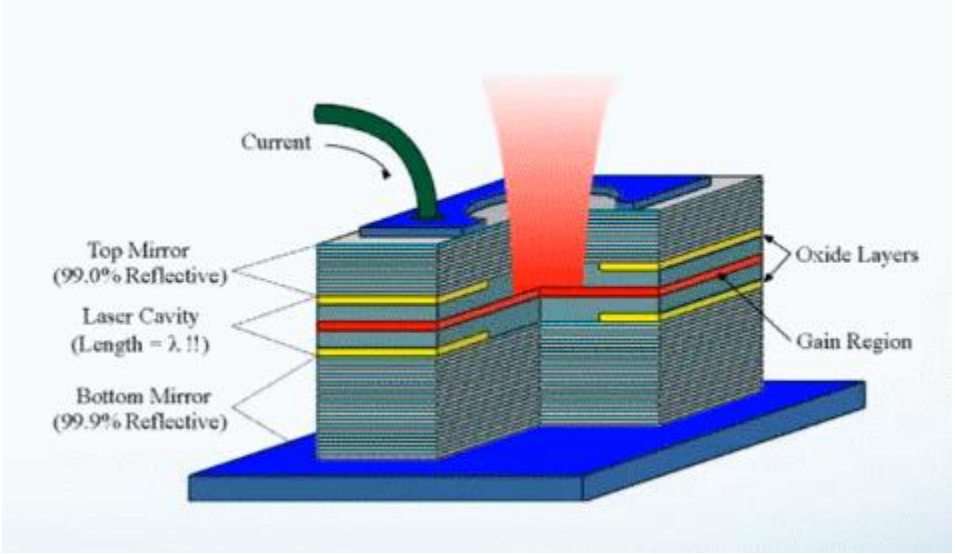
Silicon vs compound semiconductor processing



3D view of the Silicon Wafer after depositing the Poly layer. There are 2 Active Region (For PMOS and NMOS), Isolation Region (which consists Field Oxide), Gate Oxide and Poly layer.

Silicon processing tends to be planar / lateral: up to 60 billion transistors per chip





CS processing tends to be 3D: single or few special function devices (eg lasers) per chip

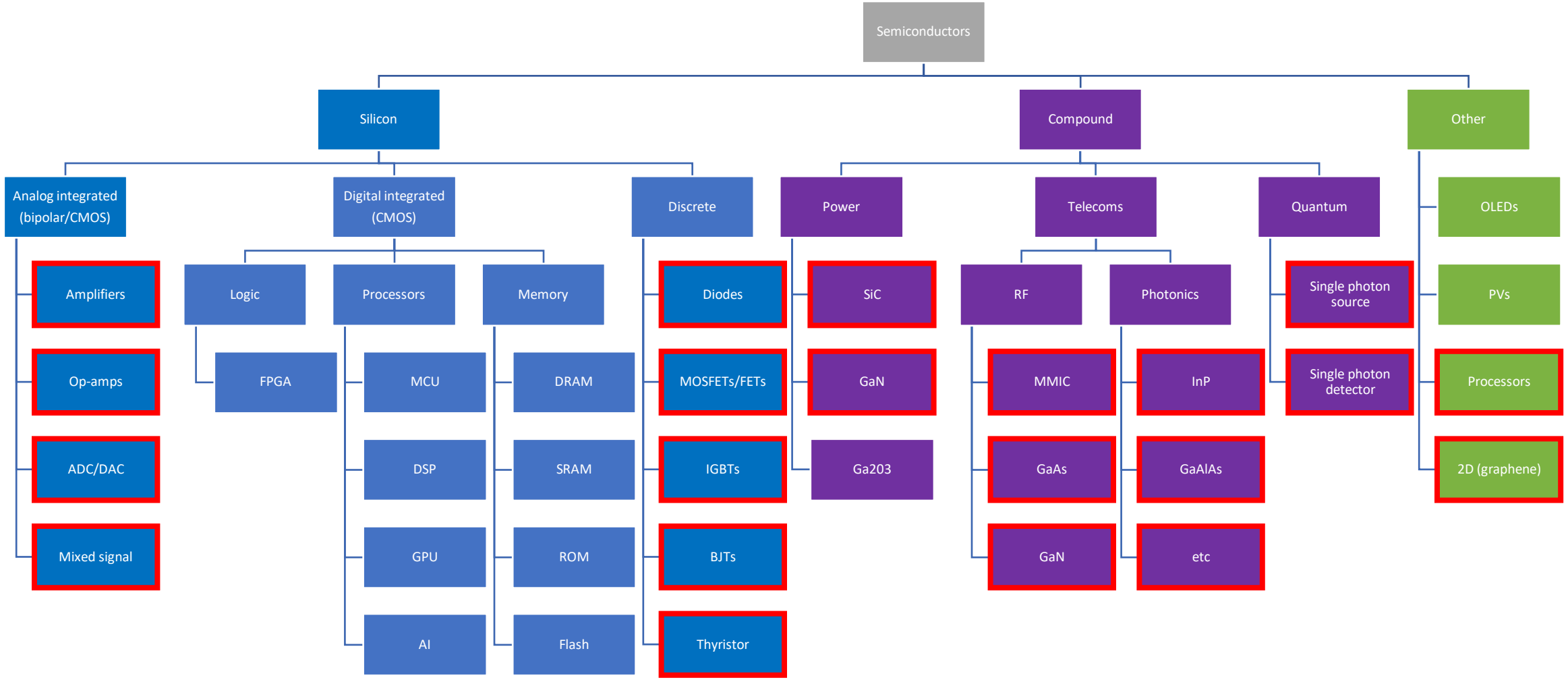
Compound semiconductors – segmented by application

Category	Typical chips	Typical applications
Power (eg GaN or SiC)	Single power transistors or arrays of power transistors	Used for power electronics in electric vehicles and smart grids
Speed (eg GaN or GaAs)	High frequency amplifier chips	Used to generate radio frequency (RF) signals for 5G, satellite communications and defence applications such as RADAR
Light (eg InP or GaAs)	Lasers, sensors, photon sources and detectors	Optical communications, missile guidance and quantum applications

‘Other’ semiconductors – segmented by application

Material / technology	Typical chips	Typical applications
OLED and AMOLED	Large area displays	Displays for laptops, smart phones and smart TVs
Perovskite	Large area solar panels	Solar panels
Thin film	Flexible computer chips – lower cost than silicon but limited functionality compared with silicon	Low-cost labelling of consumer products
2D (eg graphene)	Sensors	High precision monitoring in harsh environments such as nuclear reactors or CERN

Semiconductor taxonomy



UK fabrication capability

Semiconductor supply chains

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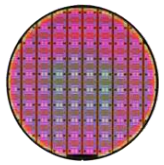
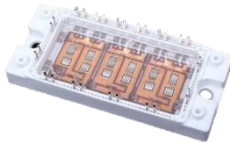
Technology | Technology

Convening | Convening | Convening | Convening

Raw materials → Etching → Packaging → Sub-assembly → Final assembly

Wafer	Die	Module (chip)	System	Applications
				 Automotive
£	££	£££	££££	 Telecoms
				 Space / Quantum
				£££££

20-25 UK fabs
capital intensive,
risk averse

20 UK packaging companies

5,000 UK companies
design and
manufacture electronic
systems

UK fab capability

Business models:

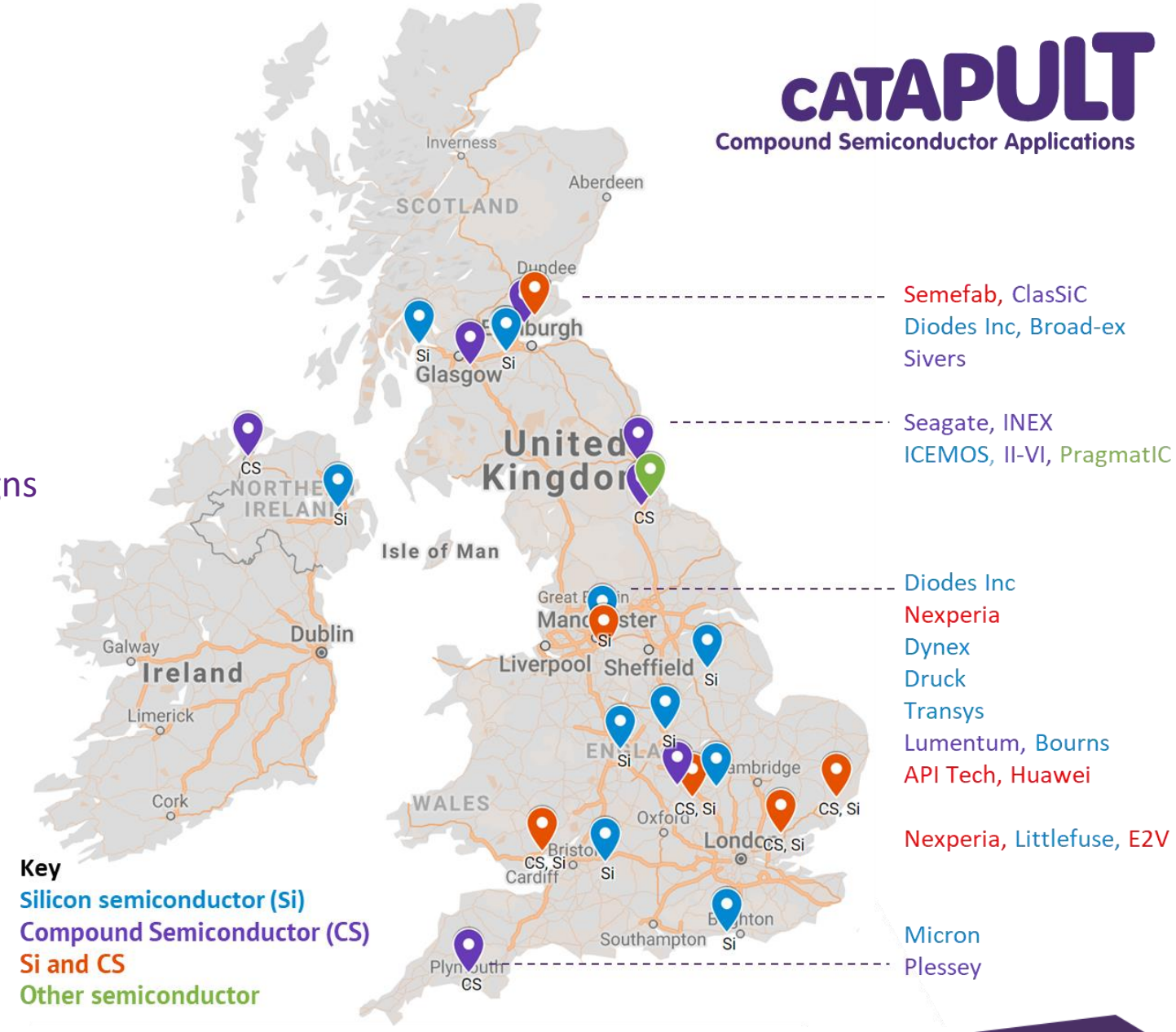
1 Integrated device manufacture (IDM)

- Research chip design and manufacturing process
- Manufacture ‘badged’ chips
- Eg Intel, Samsung, AMD

2 Open foundry

- Research manufacturing process
- Offer ‘process design kit’ (PDK) for 3rd party designs
- Manufacture chips to order, sell capacity
- Eg TSMC, Samsung

Trend: from IDM to open foundry



UK packaging capability

Packaging functions

- Attaching electrical connections to semiconductor die (to be fitted to a printed circuit board PCB)
- Attaching die directly to a PCB
- Hybrid packaging: integrating semiconductor die with passive components to create a hybrid module
- Heterogeneous integration: integrating compound semiconductor ‘chiplets’ with silicon ‘chiplets’ to create a highly functional module
- Photonic packaging: aligning optical fibres or light guides with a photonic semiconductor, such as a laser or a detector, to create a photonic module
- RF packaging: coupling RF output to an antenna or array (eg metamaterial) to radiate the RF signal

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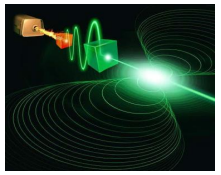
Compound Semiconductor Applications

UK system integration capability

Vehicle electrification (Net Zero)



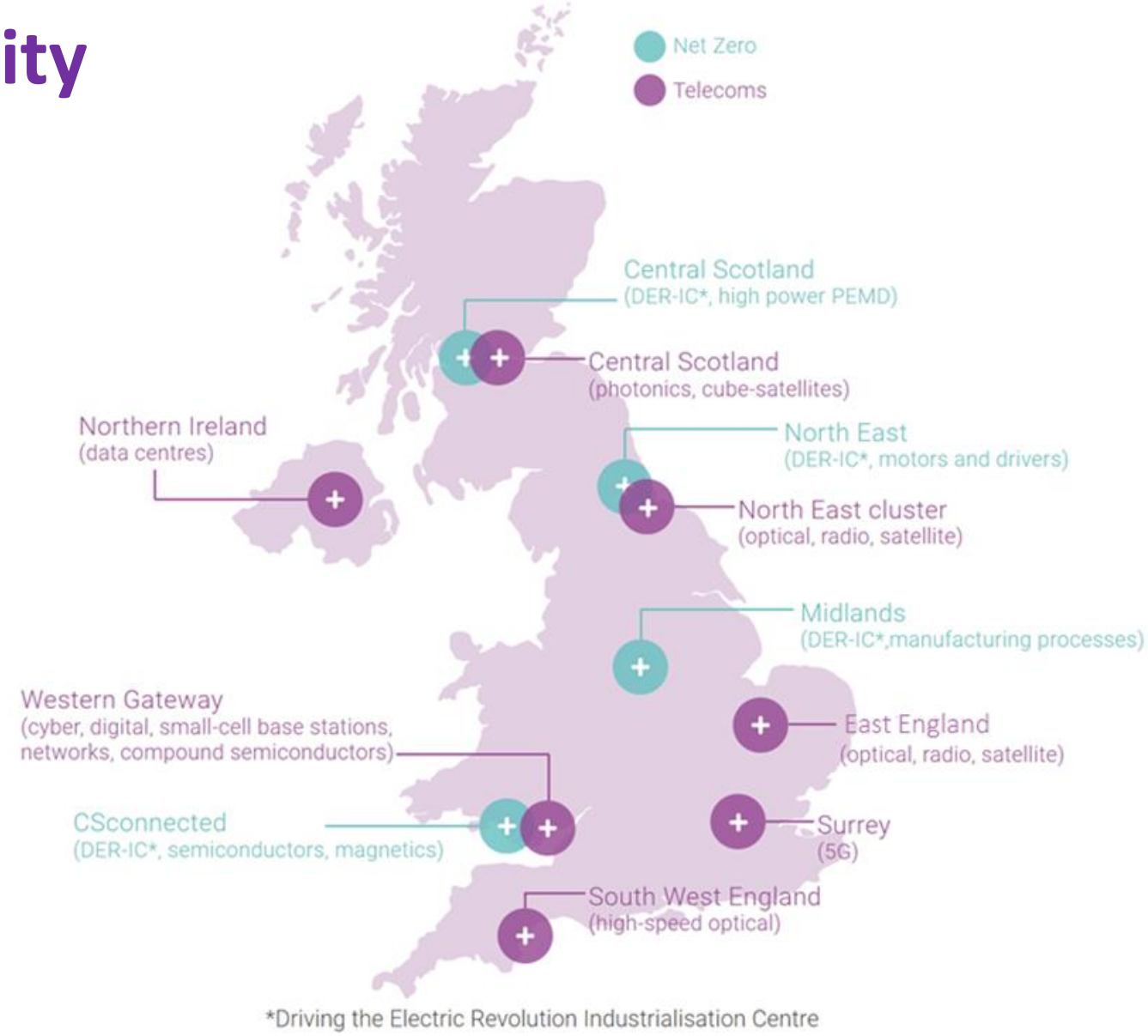
Quantum

Telecoms

Smart energy grids (Net Zero)

Space

Defence



Silicon fabrication costs

Year	Node	Silicon mask costs									No. transistors	Application
2020	5nm										59 billion	GraphCore AI
2018	7nm										7 billion	Apple A12
2017	10nm									$6-9m		
2014	16nm								$2.5-4m	$2.5-4m		
2013	20/22nm										1 billion	Apple A7
2010	28nm						$1.5-3m	$1.5-3m	$1.5-3m	$1.5-3m		
2008	40nm			$0.9-2m	$0.9-2m	$0.9-2m	$0.9-2m	$0.9-2m	$0.9-2m	$0.9-2m	47 million	Intel Atom
2006	55/65nm			$0.5-1.5m	$0.5-1.5m	$0.5-1.5m	$0.5-1.5m	$0.5-1.5m	$0.5-1.5m	$0.5-1.5m		
2003	80/90nm			$0.3-1m	$0.3-1m	$0.3-1m	$0.3-1m	$0.3-1m	$0.3-1m	$0.3-1m		
2003	110/130nm	$0.2-0.5m	$0.2-0.5m		$0.2-0.5m	$0.2-0.5m	$0.2-0.5m	$0.2-0.5m	$0.2-0.5m	$0.2-0.5m		
2000	150/180nm	$200k	$200k		$200k	$200k	$200k	$200k	$200k	$200k		
1997	250nm											
1995	350nm										5.5 million	Pentium Pro
1992	500nm											
		POWER	**MEMs**	**DRAM**	**IMAGE SENSORS**	**HIGH VOLTAGE**	**FLASH**	**RF**	**ANALOG**	**LOGIC**		

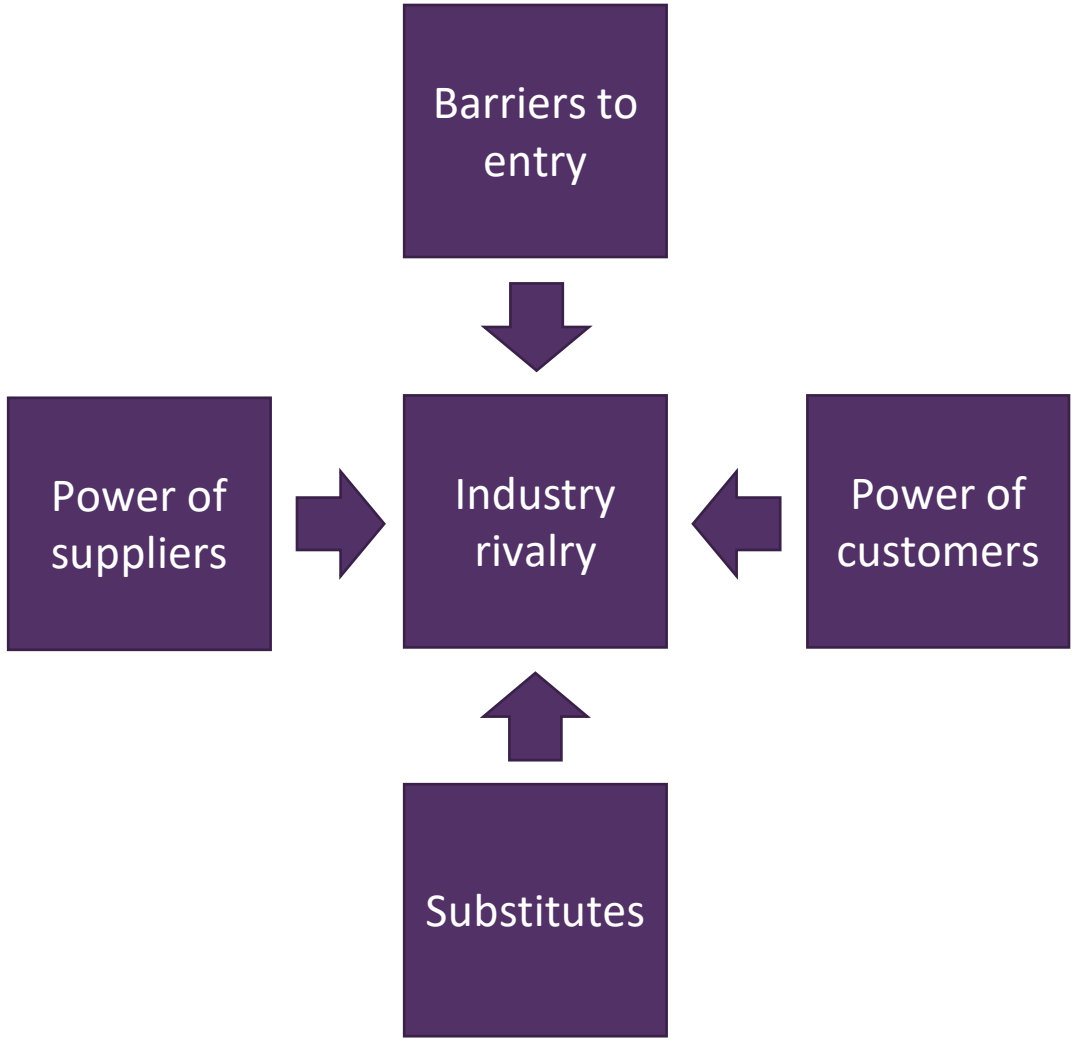
leading edge
mainstream
legacy

[The Economics of ASICs: At What Point Does a Custom SoC Become Viable? | Electronic Design]

[5 nm process - Wikipedia]

Strategic advantage

- A company (or country) has a strategic advantage if it creates the conditions to secure success in a market (or non-market sector such as defence) in the medium to long term
- A technology or material confers strategic advantage if it is essential to achieving success in a market (or non-market sector), and there are no alternatives available



[Porter's five forces analysis - Wikipedia]

UK silicon capability

Silicon category	Device / application	UK R&D	UK design	UK fabrication	Strategic advantage
Legacy > 90nm	Logic, analog, MCU, MOSFET, diode, IGBT, FLASH	High	Medium: including design houses	High: some fabs capable of 1bn devices / year	Medium: alternatives available
Mainstream 28 to 90nm	MCU, DSP, FPGA, RAM	Medium: university research	High: good MCU and ASIC design	None	High: critical to all electronic products
Leading edge < 28nm	GPU, AI, IPU, FPGA	Medium: university research	High: world leading MCU design	None	High: critical to advanced electronic products

UK compound semiconductor capability

Compound semiconductor category	Device / application	UK R&D	UK design	UK fabrication	Strategic advantage
Power electronics	MOSFETs for electric propulsion	High: over £300m invested by EPSRC since 2006	High: start-ups, SMEs and larger companies	Medium: mix of low-scale and medium-scale production	High: critical to Net Zero
RF/ microwave	RF amplifiers for 5G / RADAR	High: over £300m invested by EPSRC since 2006	High: many SMEs and a few larger companies	Medium: low-scale production	High: critical to telecoms and defence
Photonics / quantum	Lasers + detector for optical comms	High: over £400m invested by EPSRC since 2006	High: many SMEs and a few large companies	Medium: high-scale wafer production but off-shored packaging	High: critical to telecoms, quantum and defence

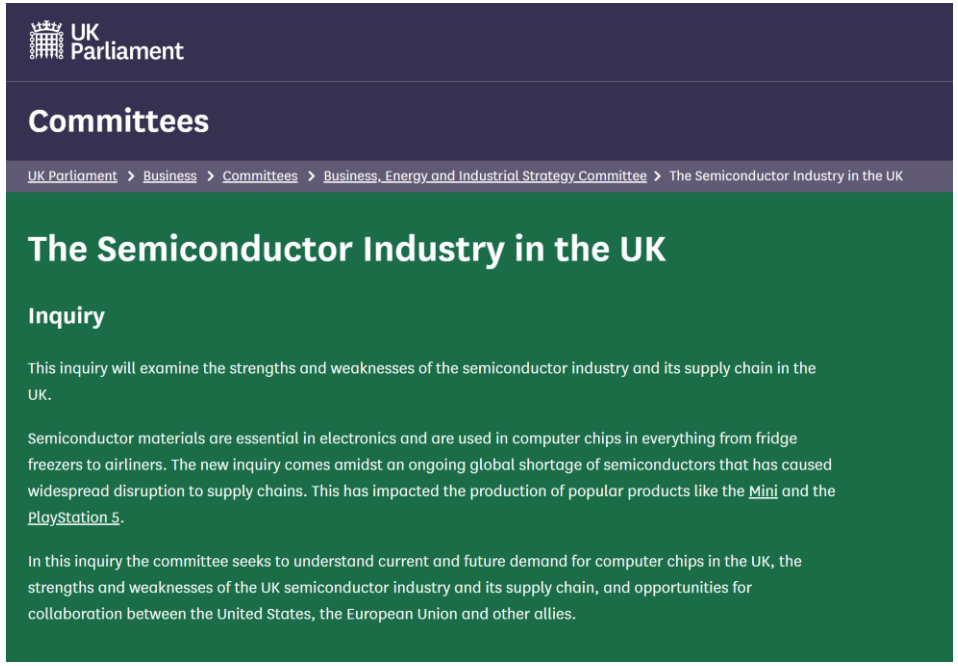
UK ‘other’ semiconductor capability

Other category	Device / application	UK R&D capability	UK design	UK fabrication	Strategic advantage
OLED	Displays	Low	Medium	None	Low: alternatives available
Perovskites	Solar cells	High: good research at a few universities	Medium	None	Low: alternatives available
Thin film	Flexible MCU	High: leading university research	High: supported by silicon design ecosystem	High: world leading thin film fabrication	Medium: potentially disruptive technology
2D	Sensors	High: graphene and other 2D materials	High: mostly start-ups as it’s an emerging technology	High: early stage companies	Medium: potentially disruptive technology

Integrated Review framework

Category	Definition
OWN	Where the UK has leadership and ownership of new developments, from discovery to large-scale manufacture and commercialisation. This will always involve elements of collaboration and access.
ACCESS	Where the UK can provide unique contributions that allow us to collaborate with others to achieve our goals.
COLLABORATE	Where the UK will seek to acquire critical S&T from elsewhere, through options, deals and relationships.

Conclusions: submission deadline 14 June 2022



UK Parliament

Committees

UK Parliament > Business > Committees > Business, Energy and Industrial Strategy Committee > The Semiconductor Industry in the UK

The Semiconductor Industry in the UK

Inquiry

This inquiry will examine the strengths and weaknesses of the semiconductor industry and its supply chain in the UK.

Semiconductor materials are essential in electronics and are used in computer chips in everything from fridge freezers to airliners. The new inquiry comes amidst an ongoing global shortage of semiconductors that has caused widespread disruption to supply chains. This has impacted the production of popular products like the Mini and the PlayStation 5.

In this inquiry the committee seeks to understand current and future demand for computer chips in the UK, the strengths and weaknesses of the UK semiconductor industry and its supply chain, and opportunities for collaboration between the United States, the European Union and other allies.

[The Semiconductor Industry in the UK - Committees - UK Parliament]

Deadline: 14 June 2022

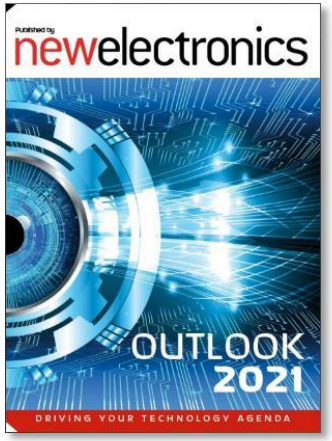
Thought leadership, click to view…

2017

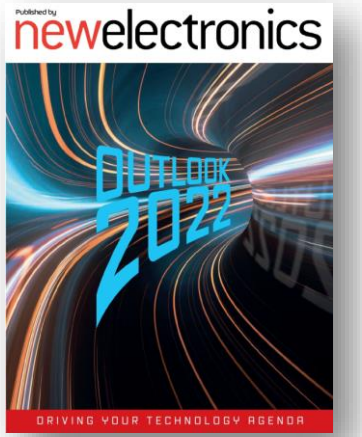
2017

2017

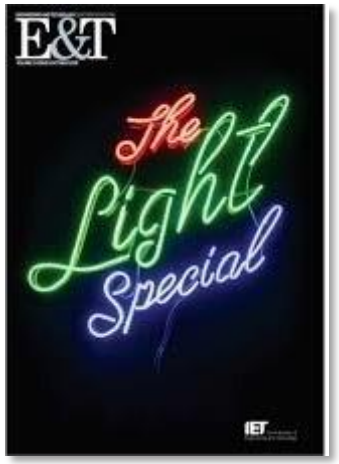
2018



2020



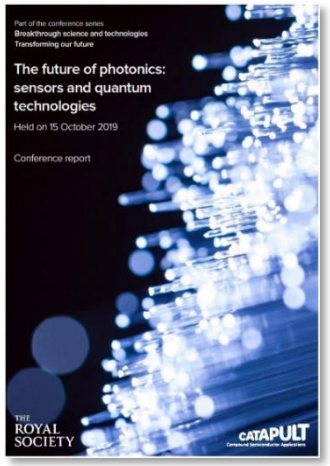
2021



2018

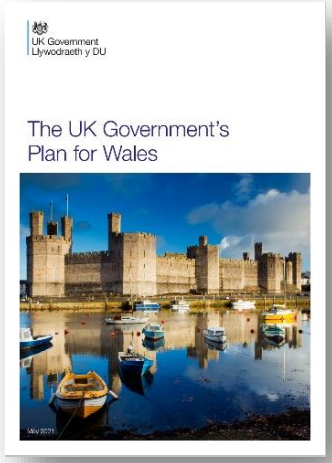
2019

2019



2019

2020



2021

In the news, click to view…

26 Mar 2020

3 Nov 2020

27 Nov 2020

9 Dec 2020

29 Mar 2021

7 Sep 2021

30 Aug 2021

2022

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The CSA Catapult is a member of CS-Connected – the South Wales compound semiconductor cluster

www.csconnected.com

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